



Functional neuroimaging

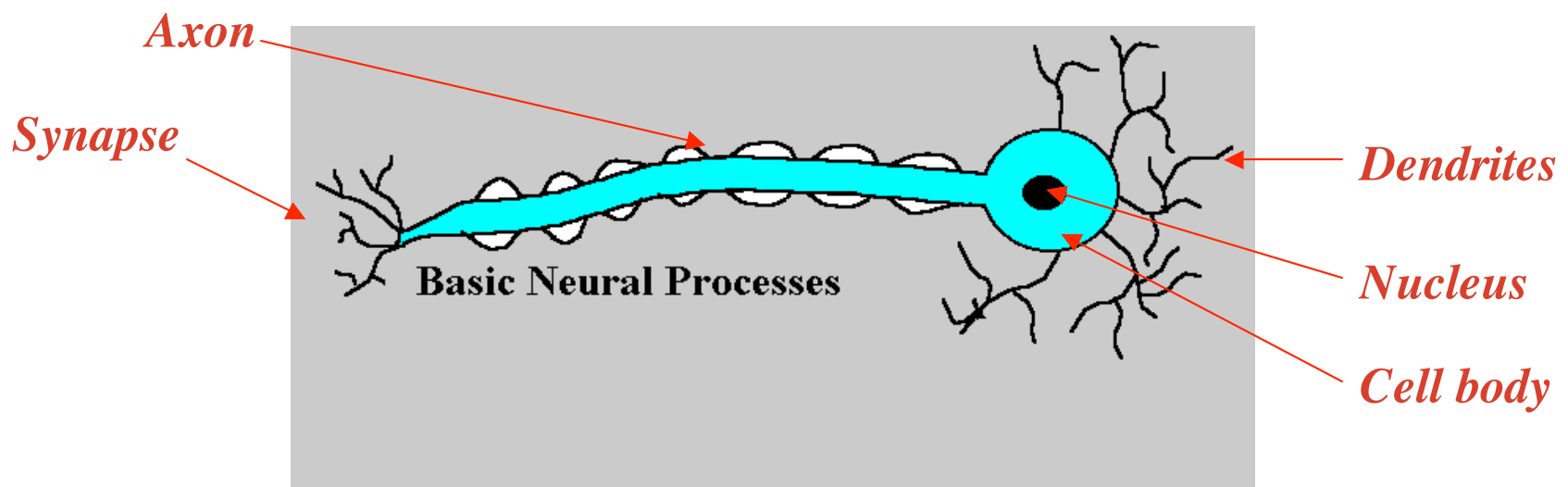
- Imaging brain function in real time (not just the structure of the brain).

SHOUT
SHARE IT



The brain is *bloody* & *electric*

- Blood
 - **increase in neuronal activity → increase in metabolic demand for glucose and oxygen → increase in cerebral blood flow (CBF) to the active region**
- Electricity
 - **the brain works because neurons communicate with each other and they do this by sending out tiny electrical impulses**
- Blood is an indirect, slow (because blood flows slowly), measure of neural activity.
- Electricity is a direct measure of neural activity





Non-invasive
recording from
human brain
(Functional
brain imaging)

Hemodynamic
techniques

Positron emission
tomography
(PET)

Excellent spatial
resolution (~1-2mm)
Poor temporal
resolution (~1sec)

Functional magnetic
resonance imaging
(fMRI)

Electro-
encephalography
(EEG)

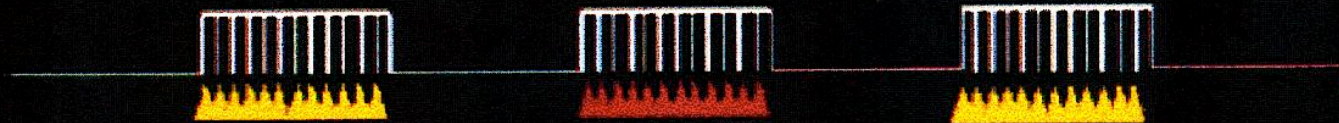
Poor spatial
resolution (esp. EEG)
Excellent temporal
resolution (<1msec)

Electro-magnetic
techniques

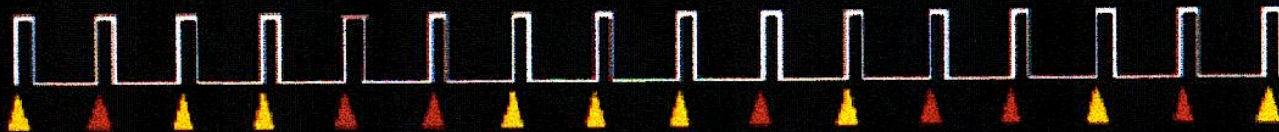
Magneto-
encephalography
(MEG)

Experimental designs for hemodynamic techniques

BLOCKED:



SPACED MIXED TRIAL:



RAPID MIXED TRIAL:

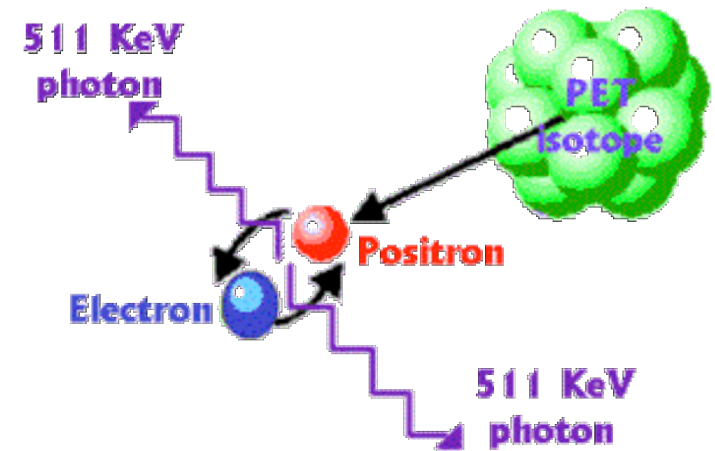




PET

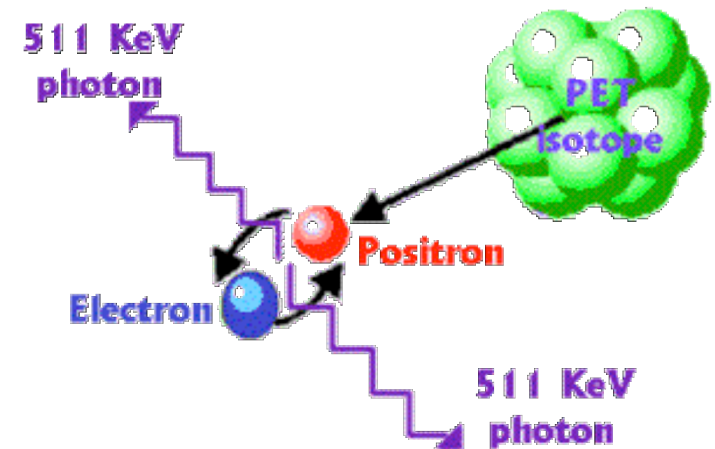
PET (Positron Emission Tomography)

- Radioactive labeling of some compound that is familiar to the body (such as glucose or water).
- The radioactive material is administered to the subject.
- PET images the electromagnetic radiation induced by the decay of the PET radioisotopes.
 - The chosen radioactive material must have a short half-life (must decay quickly).
- PET radioisotopes emit a positron (a positively charged electron) in the process of decay. When this positron collides with an electron, the 2 particles annihilate each other, and produce 2 photons traveling in opposite directions. This induces electromagnetic radiation which is what can be detected externally and is used to measure both the quantity and the location of the positron emitter.



PET (Positron Emission Tomography)

- Dependent measure: regional Cerebral Blood Flow (rCBF).
- Spatial resolution about 4mm throughout the brain.
- Temporal resolution very bad (~30-40 sec).
 - **Randomization is impossible (trials cannot be distinguished from each other).**
 - **Blocked design is necessary.**



PET scanner





PET pros and cons

PRO

- Very good spatial resolution

CONs

- Basically no temporal resolution
- Invasive.
 - **These days it's hard to get human subjects approval for PET studies, given that noninvasive alternatives exist: fMRI (based on MRI).**

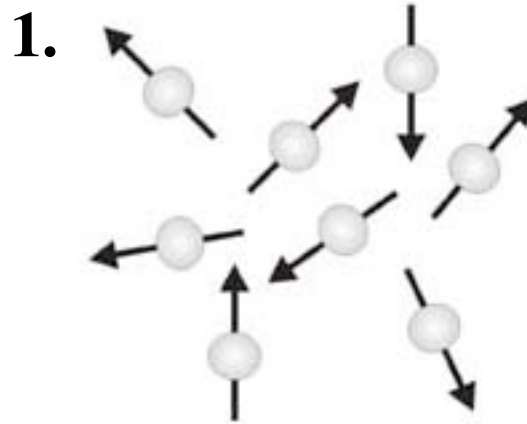


Magnetic Resonance Imaging (MRI) and functional MRI

Basics of MRI

Our bodies are mostly water and have a high concentration of hydrogen nuclei.

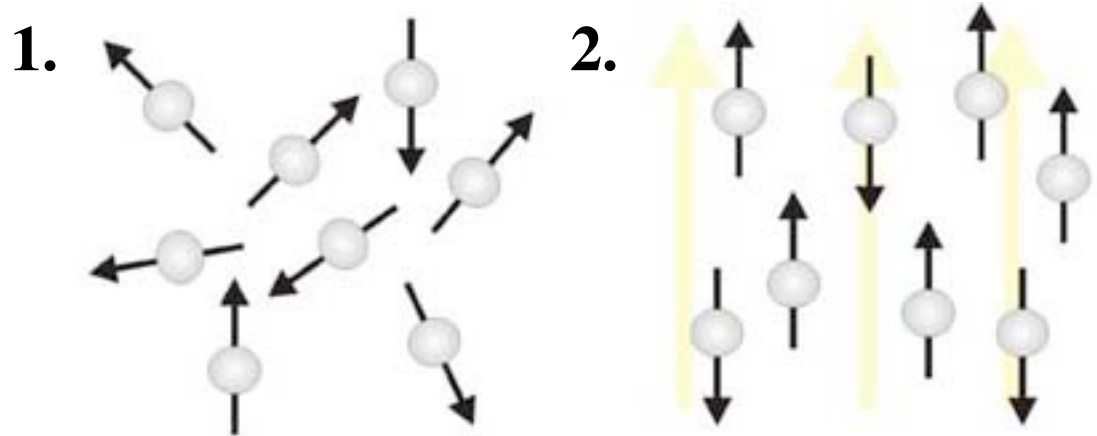
1. The nuclei of hydrogen atoms (called protons) normally point randomly in different directions.



Basics of MRI

Our bodies are mostly water and have a high concentration of hydrogen nuclei.

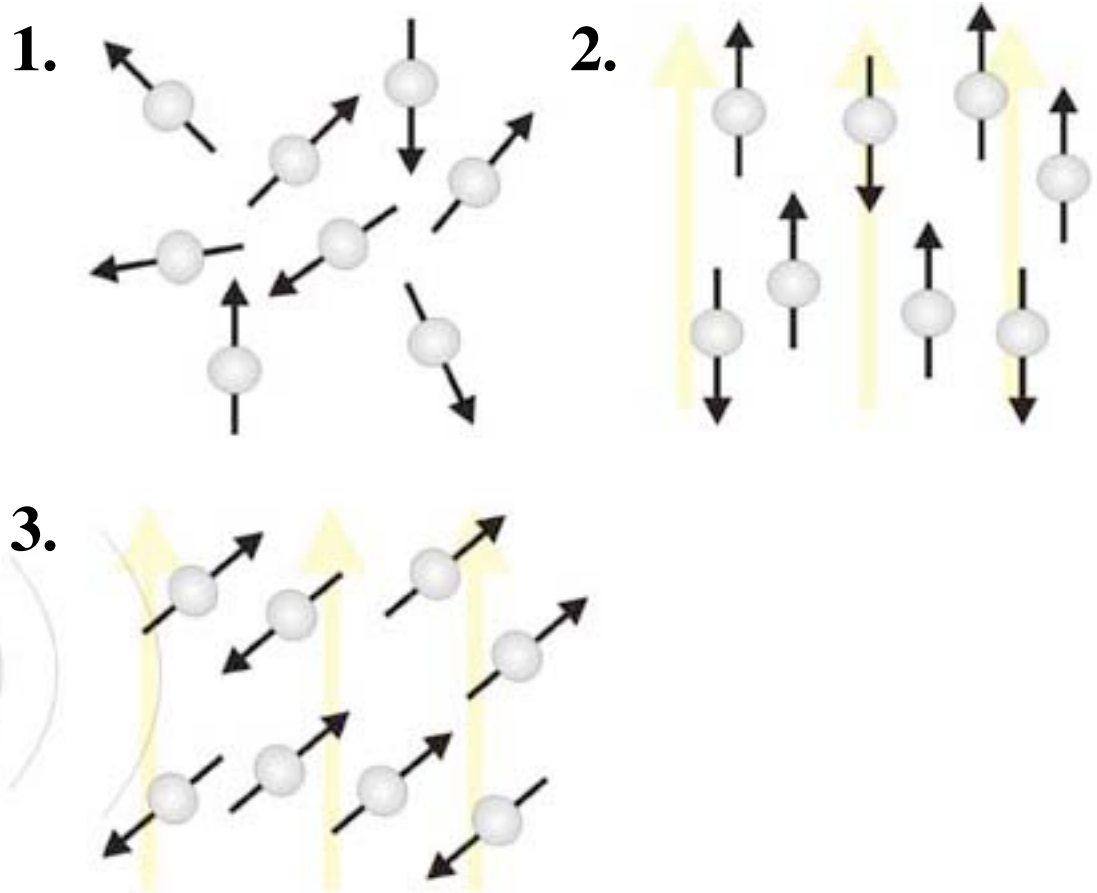
2. However, when exposed to a strong static magnetic field, the nuclei line up in parallel formation, like rows of tiny magnets. In an MRI set-up, a strong external static magnetic field is applied across the brain in order to line up the hydrogen nuclei. (This field can be up to 80 000 times stronger than the earth's magnetic field.)



Basics of MRI

Our bodies are mostly water and have a high concentration of hydrogen nuclei.

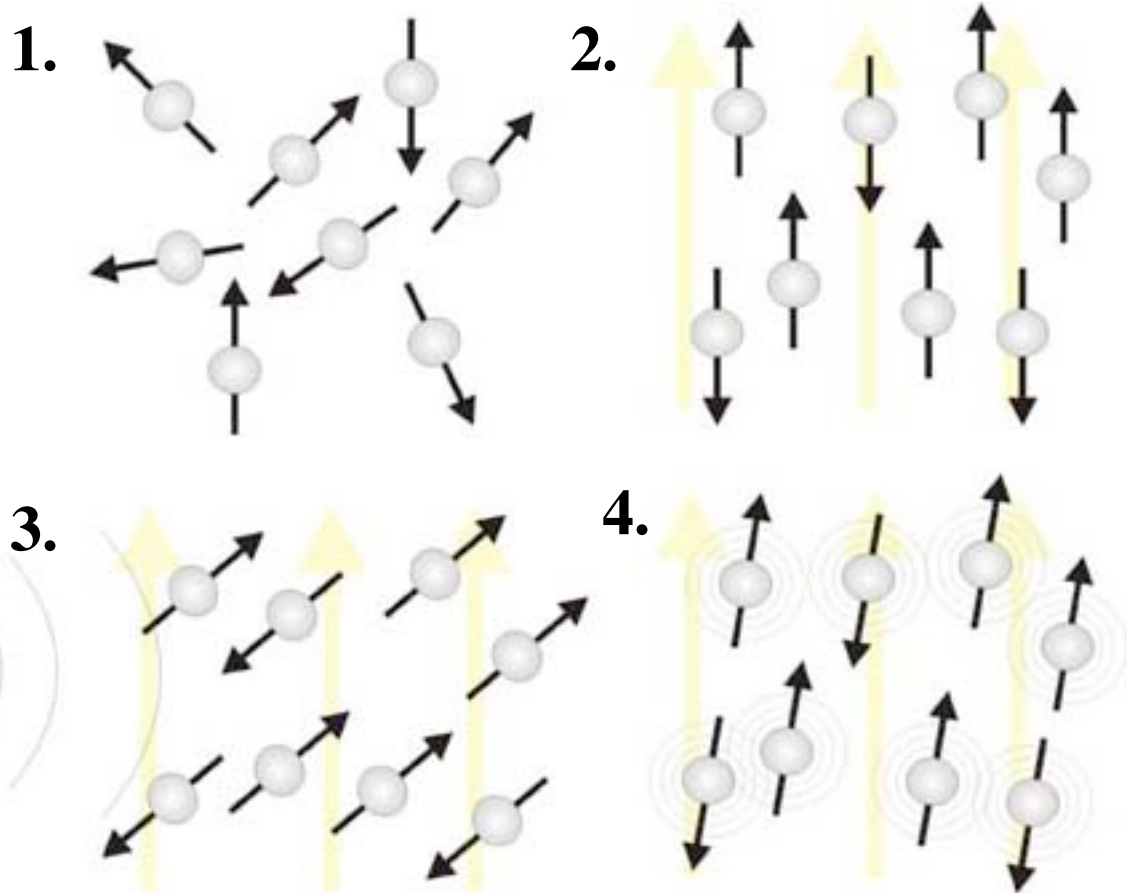
-
-
3. Then this parallel formation, called *equilibrium*, is disturbed by sending out radio waves from the MRI machine



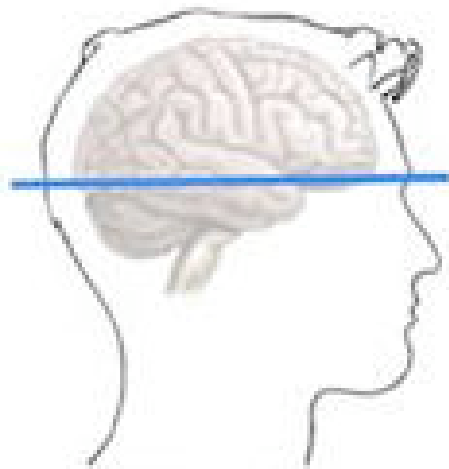
Basics of MRI

Our bodies are mostly water and have a high concentration of hydrogen nuclei.

4. As the hydrogen nuclei fall back into alignment, they produce a detectable radio signal. MRI signal decay rates (T2s) are different for different biological tissues. For example, tissues that contain little or no hydrogen (such as bone) appear black. Those that contain large amounts of hydrogen (such as the brain) produce a bright image.

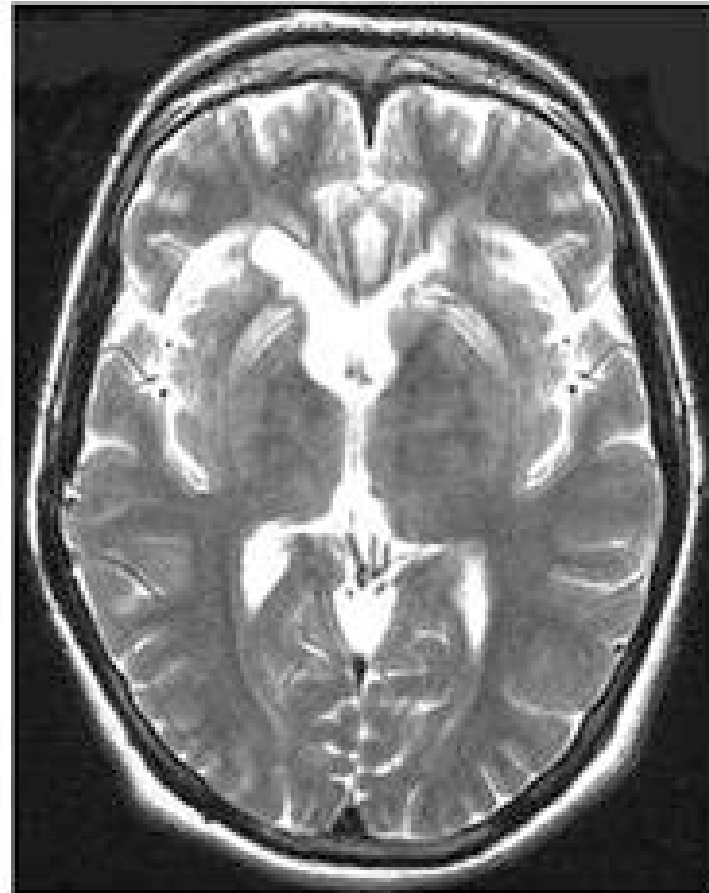


Basics of MRI



Level
of section

MRI of brain



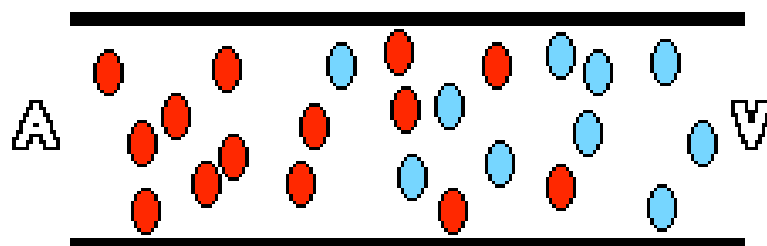


Functional MRI (fMRI)

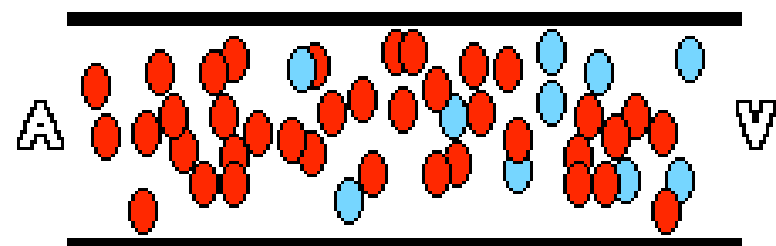
- MR has the capability to measure parameters related to several neural physiological functions, including:
 - **changes in various metabolic byproducts**
 - **blood flow**
 - **blood volume**
 - **blood oxygenation**

Functional MRI (fMRI)

- Blood Oxygenation Level Dependent (BOLD) signal
 - **Blood is more oxygenated in an activated region of the brain than in a nonactivated region.**
 - **Oxyhemoglobin and deoxyhemoglobin differ in their magnetic susceptibility: Deoxy Hb has a higher magnetization decay rate than does oxy Hb.**



Normal Flow

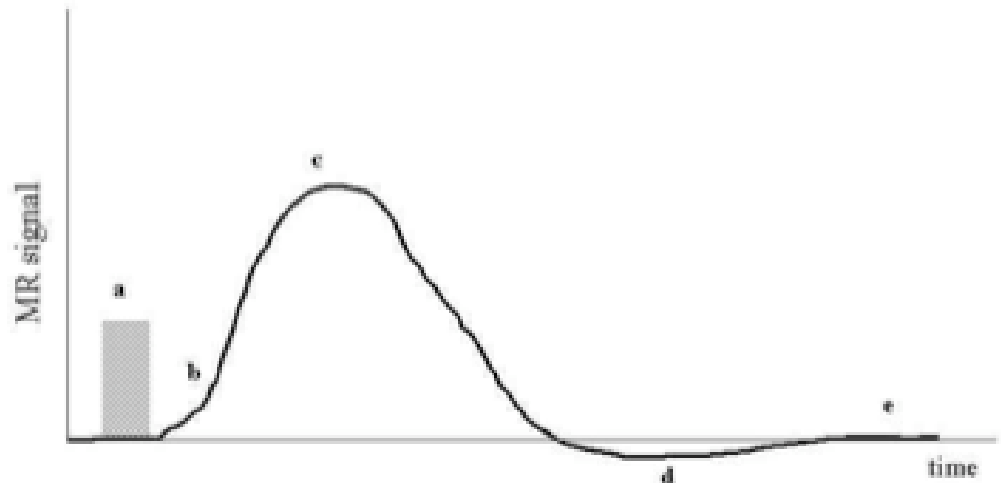


High Flow

● Oxyhemoglobin
● Deoxyhemoglobin

Functional MRI (fMRI)

- No radioactive tracers are needed.
- Spatial resolution: 3-6mm (in most applications).
- Temporal resolution: in the order of seconds.
 - **Fast enough to distinguish between trials (i.e. event-related designs and randomization are possible)**
 - **Not fast enough to distinguish between the activation patterns associated with different stages of stimulus processing.**
- Hemodynamic lag (3-6 seconds):
 - a: short stimulus
 - b. rise, 6-9 sec
 - c. return to baseline, 8-20sec
 - d. undershoot



The subtraction method

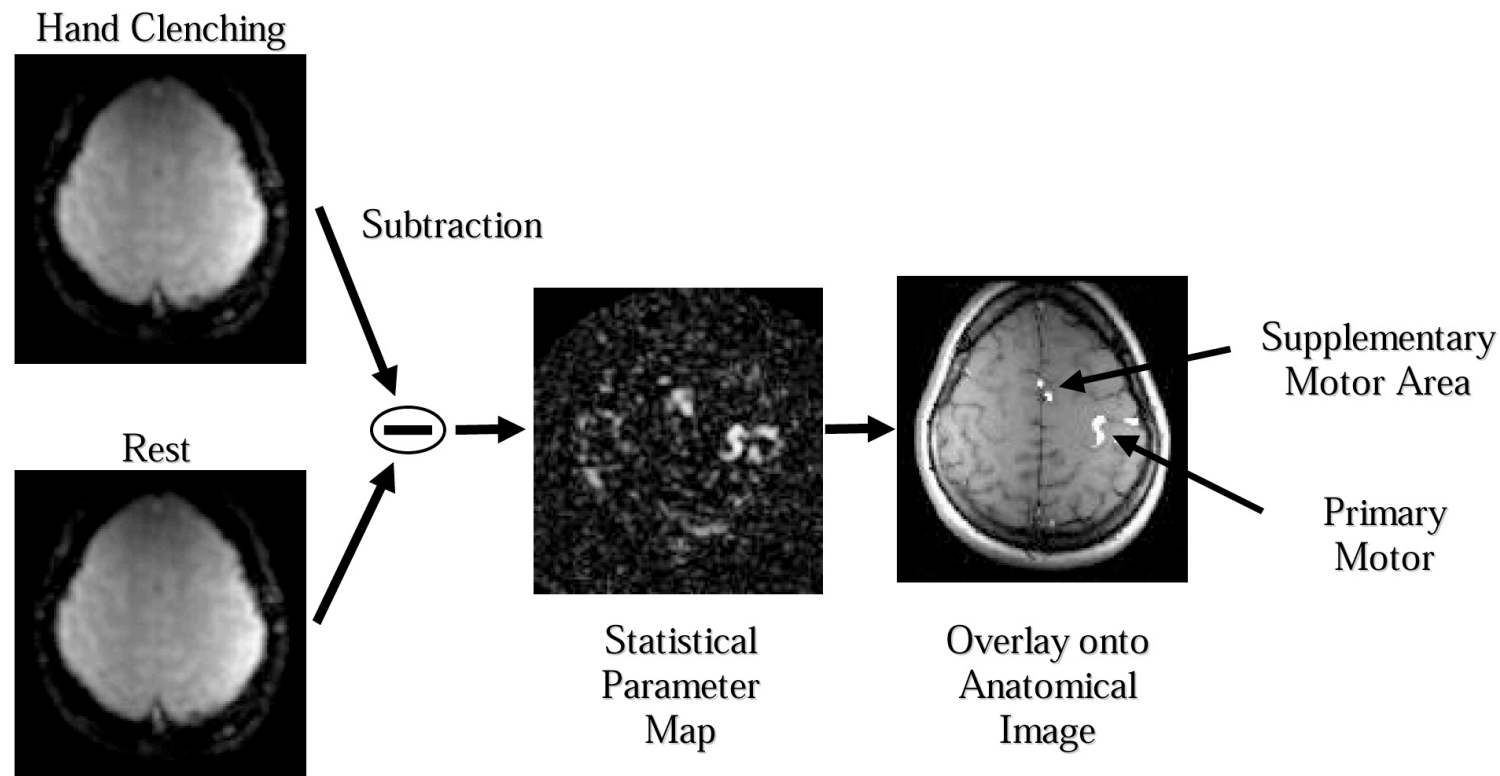


Figure 9. Graphical description of a functional MRI experiment: images from two behavioral conditions are subtracted to yield regions of brain activity. In this case, a hand clenching task was used to define the primary and supplementary motor control areas in the brain.

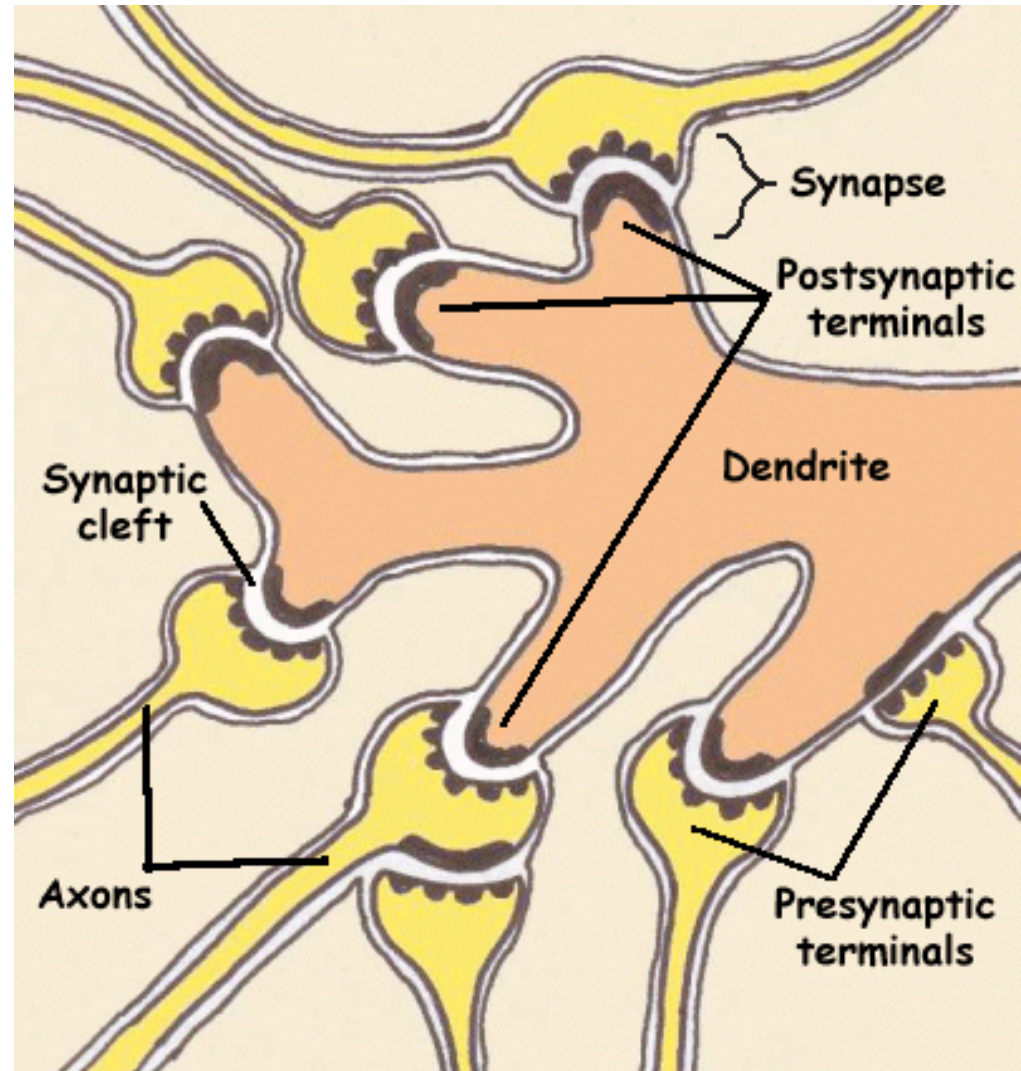
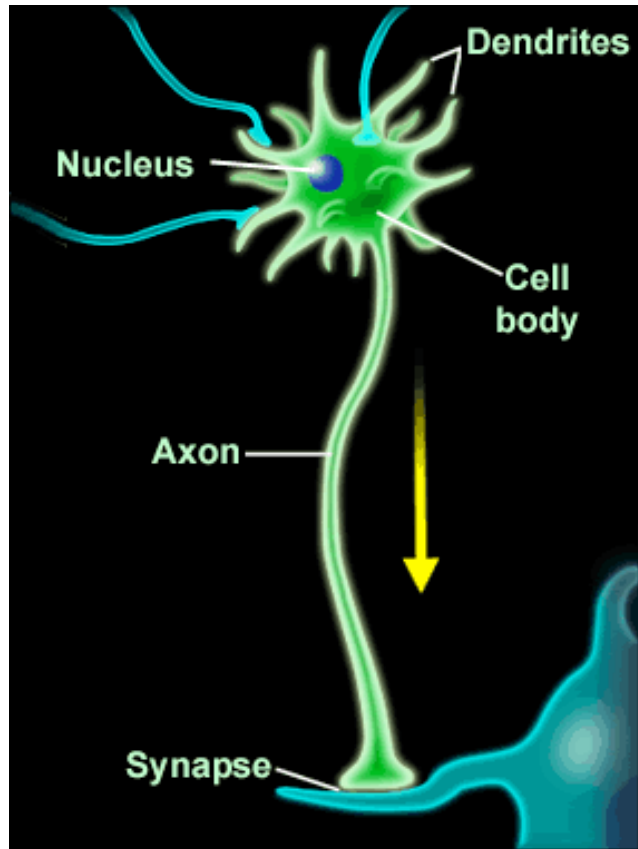


Electromagnetism: Electroencephalography (EEG) and Magnetoencephalography (MEG)

Electromagnetism

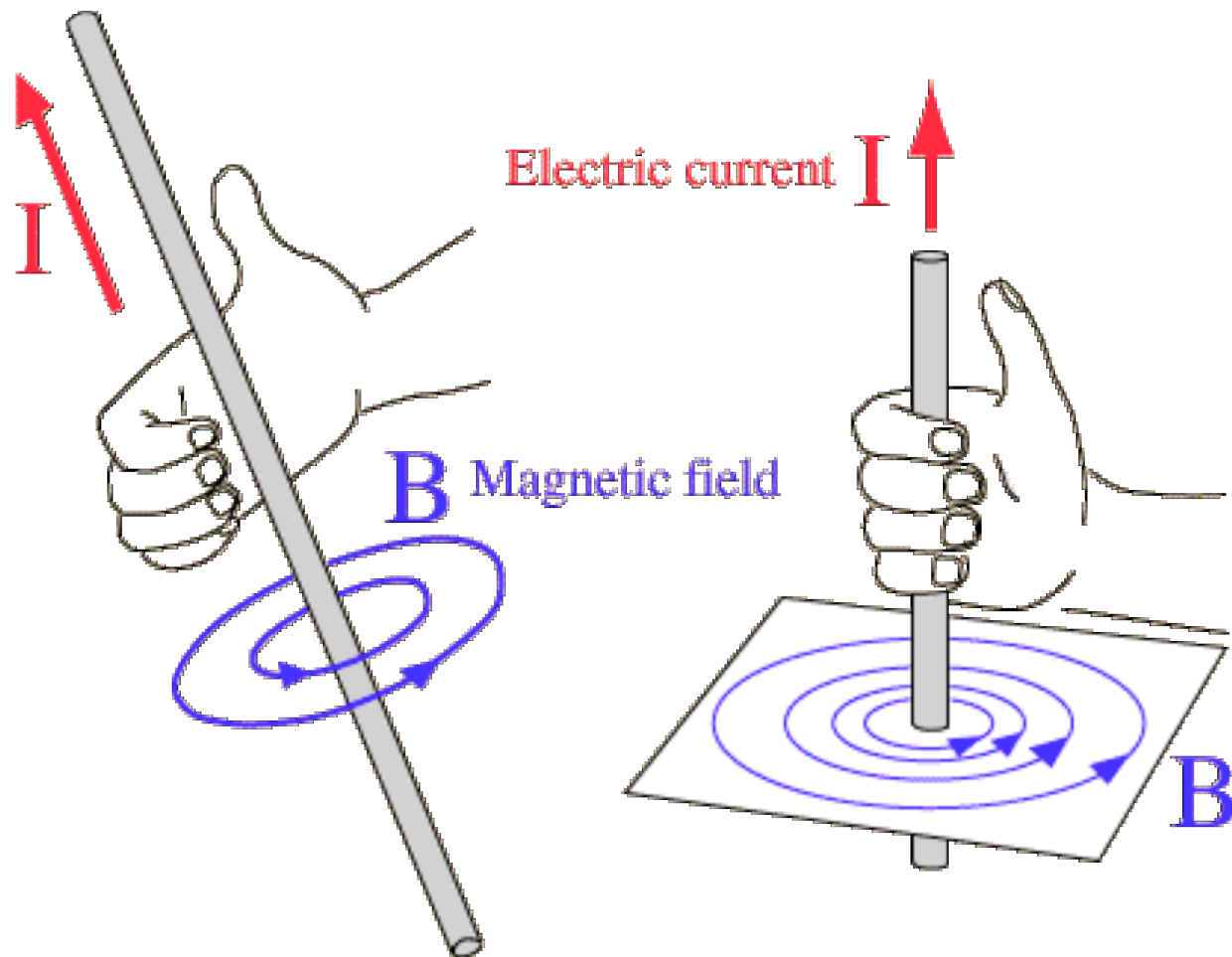
- Millisecond temporal resolution.
- Neurons communicate with each other thousands of times per second by sending each other tiny electrical impulses
- Populations of neurons are connected into networks
- When networks fire *in synchrony*, the dynamics of the electric activity can be detected and recorded outside the skull.

Main source of the signal: Post-synaptic current flow along the dendrites of (pyramidal) nerve cells



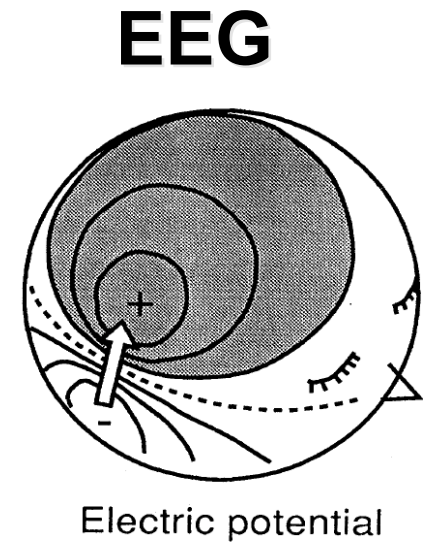
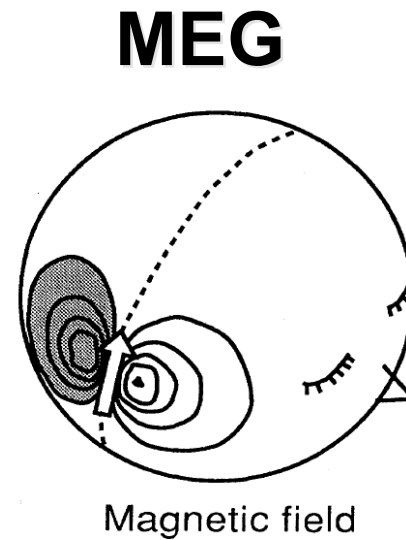
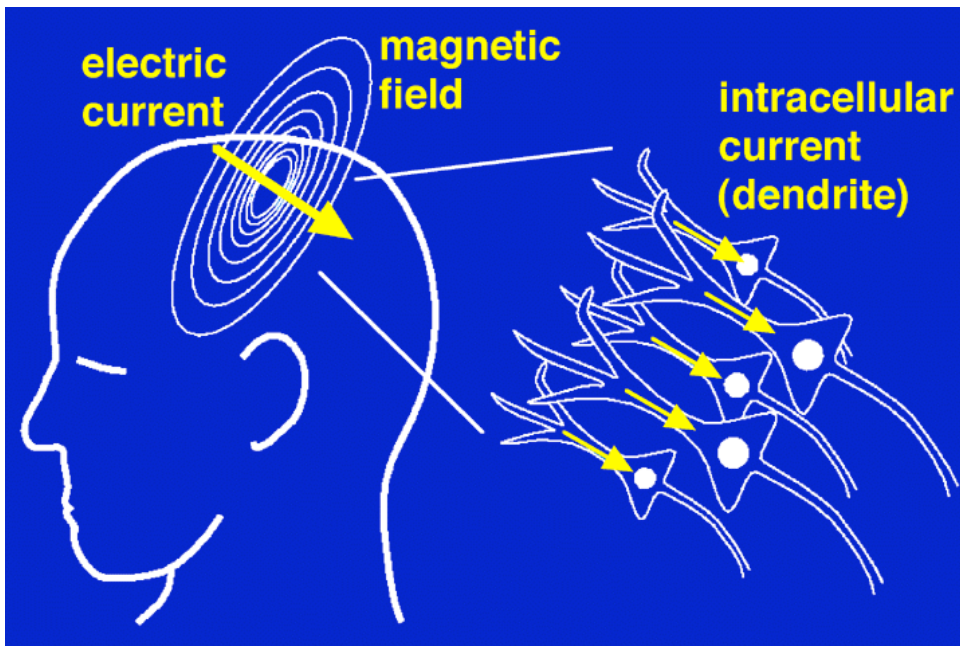
An electric current creates a magnetic field around it.

The right-hand rule: When the thumb of the right hand is pointing in the direction of the current, the fingers of the right hand curl in the direction of the magnetic field



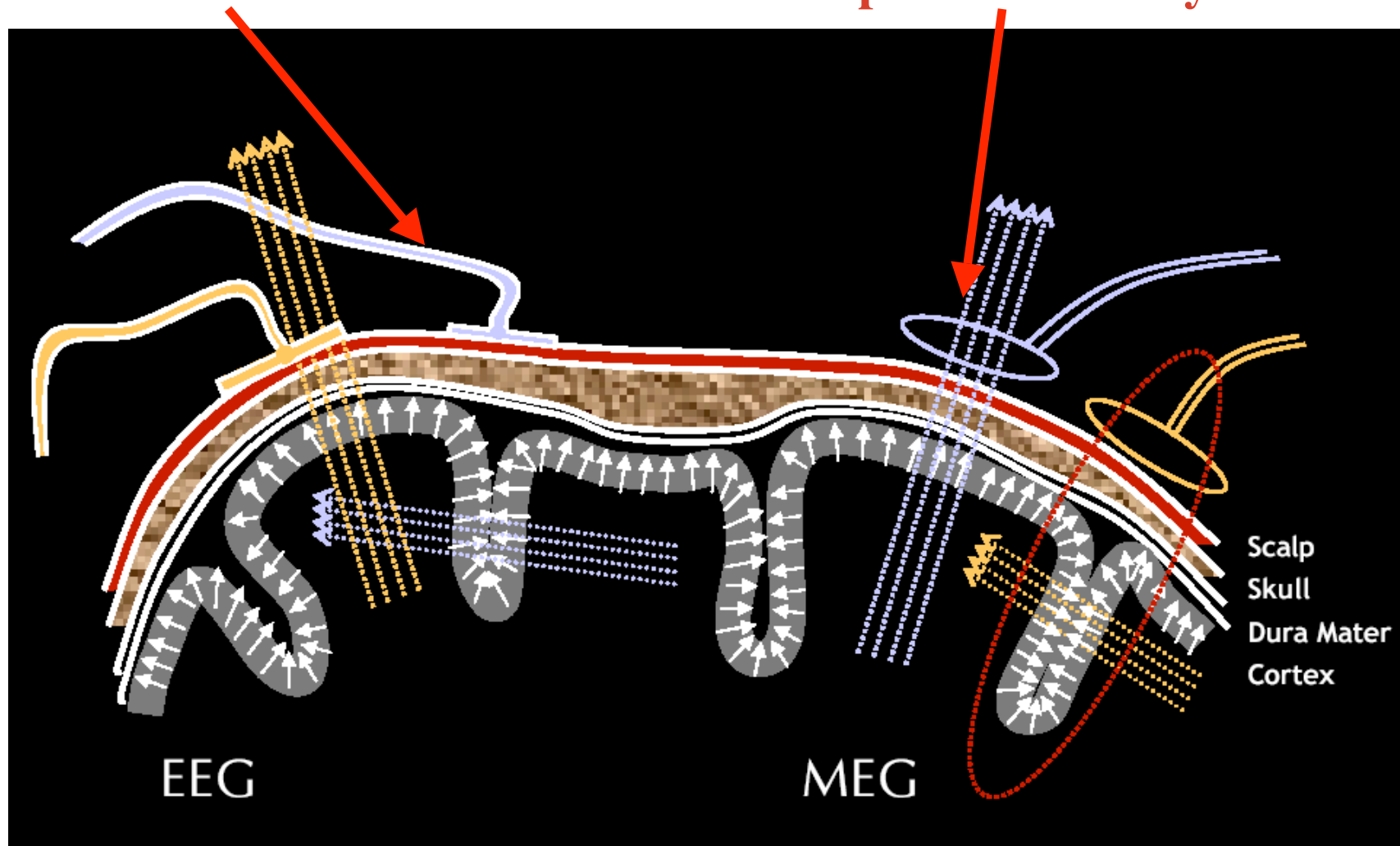
Electromagnetism

- EEG (electroencephalography): electric potentials
- MEG (magnetoencephalography): magnetic fields



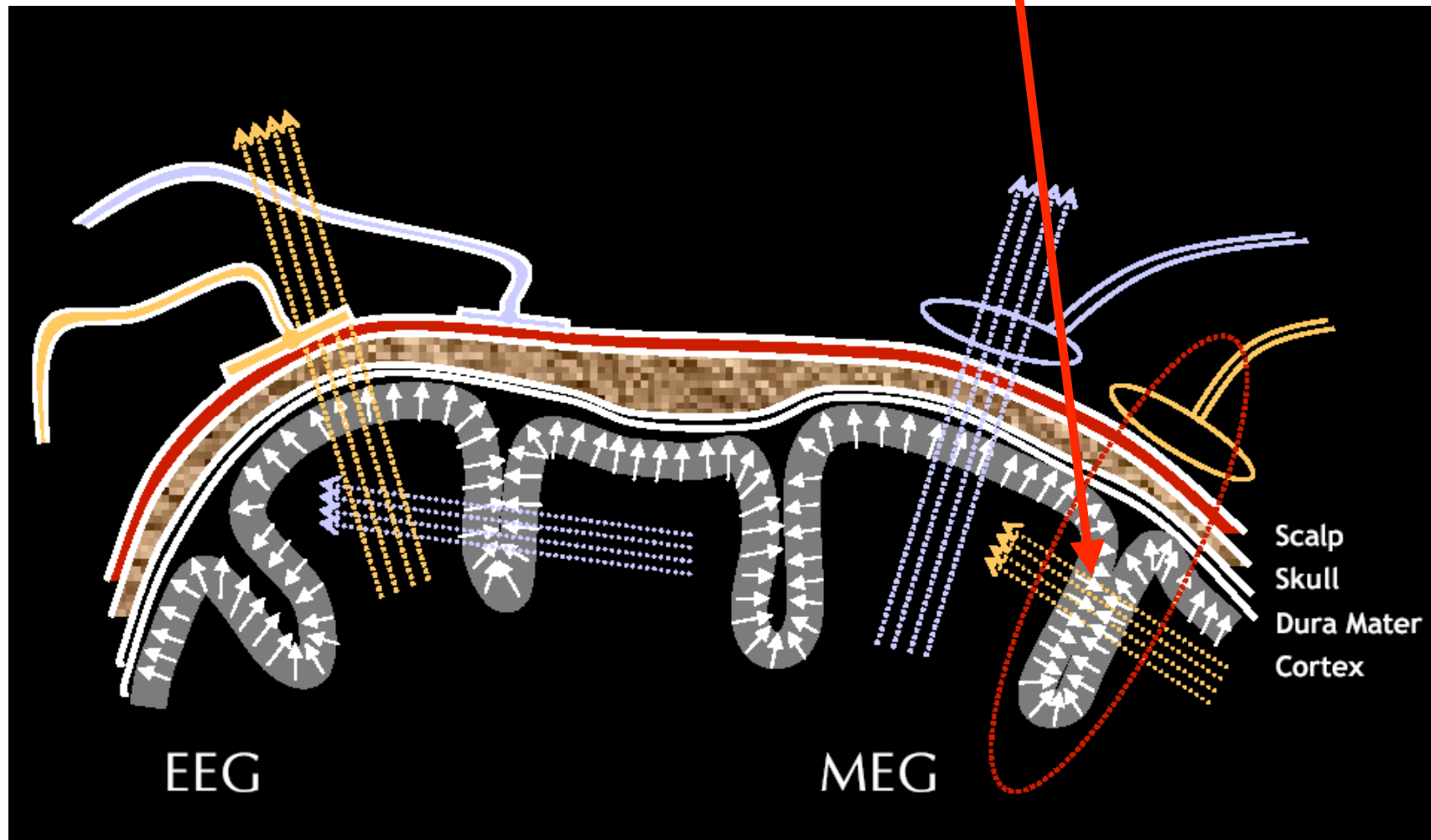
EEG electrodes on the scalp

**MEG sensors outside the head,
in a tank containing liquid
helium to enhance
superconductivity**



Source: <http://www.allgpsy.unizh.ch/graduate/mat/180102/Lecture1.pdf>

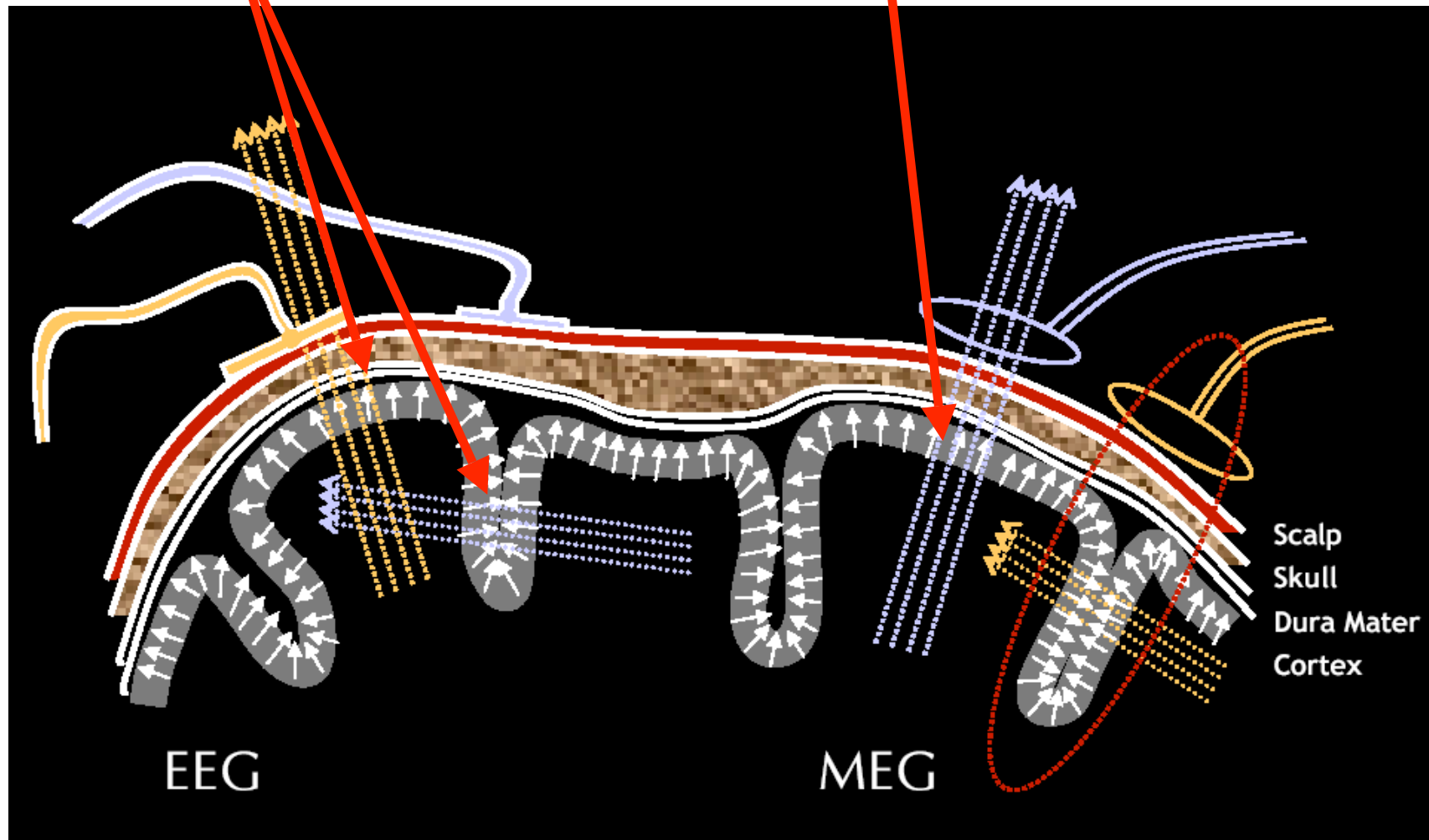
MEG signal is dominated by currents oriented tangential to the skull.

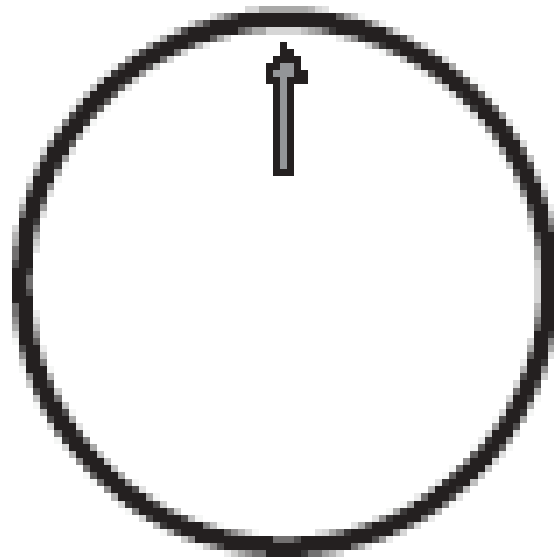


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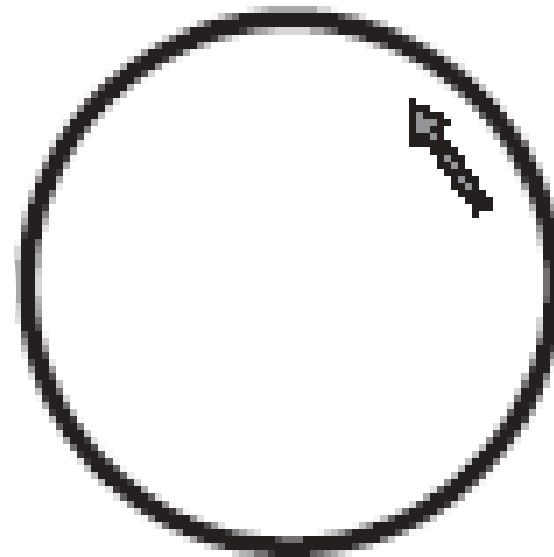
EEG picks up tangentially and radially oriented currents equally.

Currents oriented perfectly radial to the skull are missed in MEG. But there is very little signal that is so perfectly radial.





radial
source



tangential
source

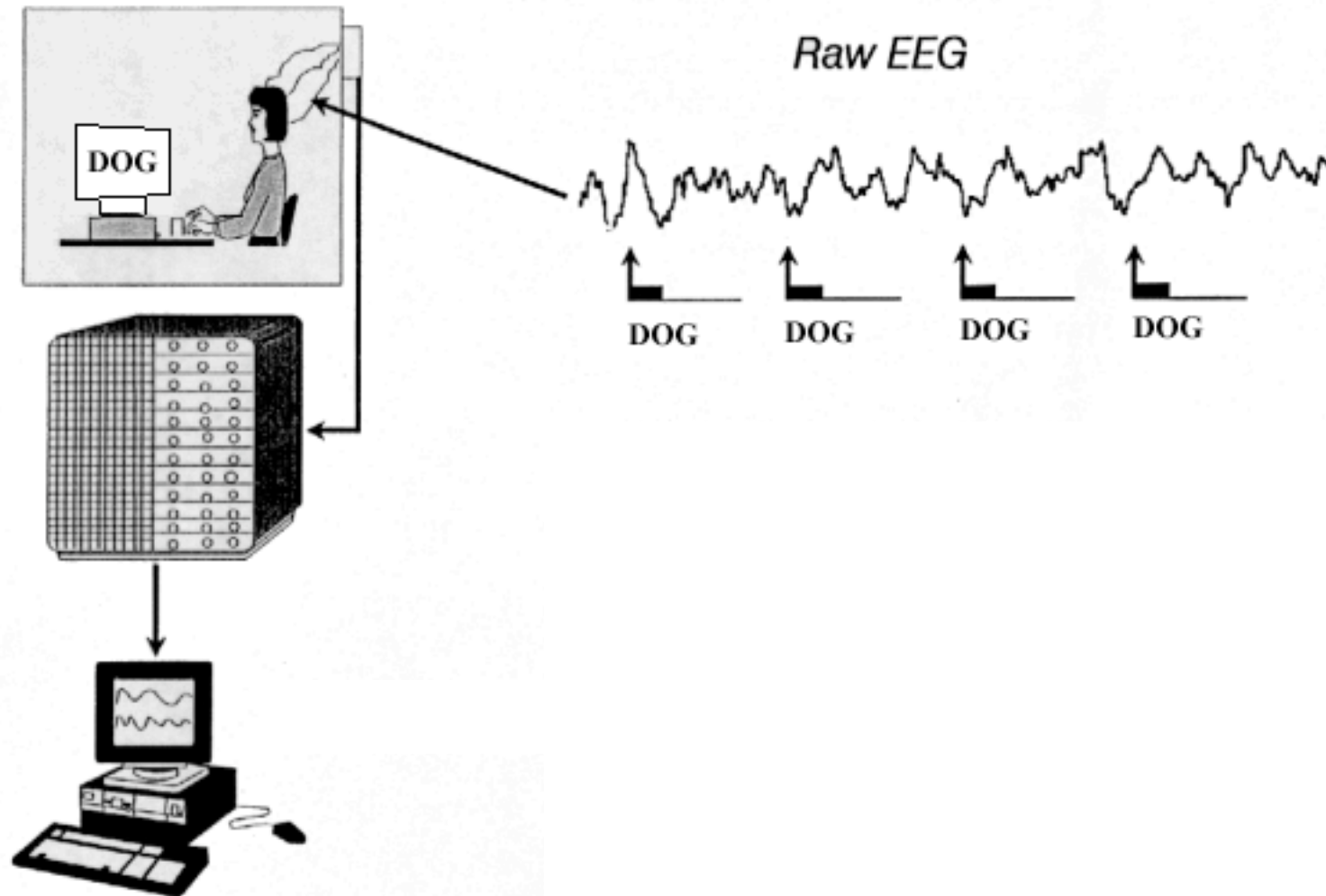
MEG



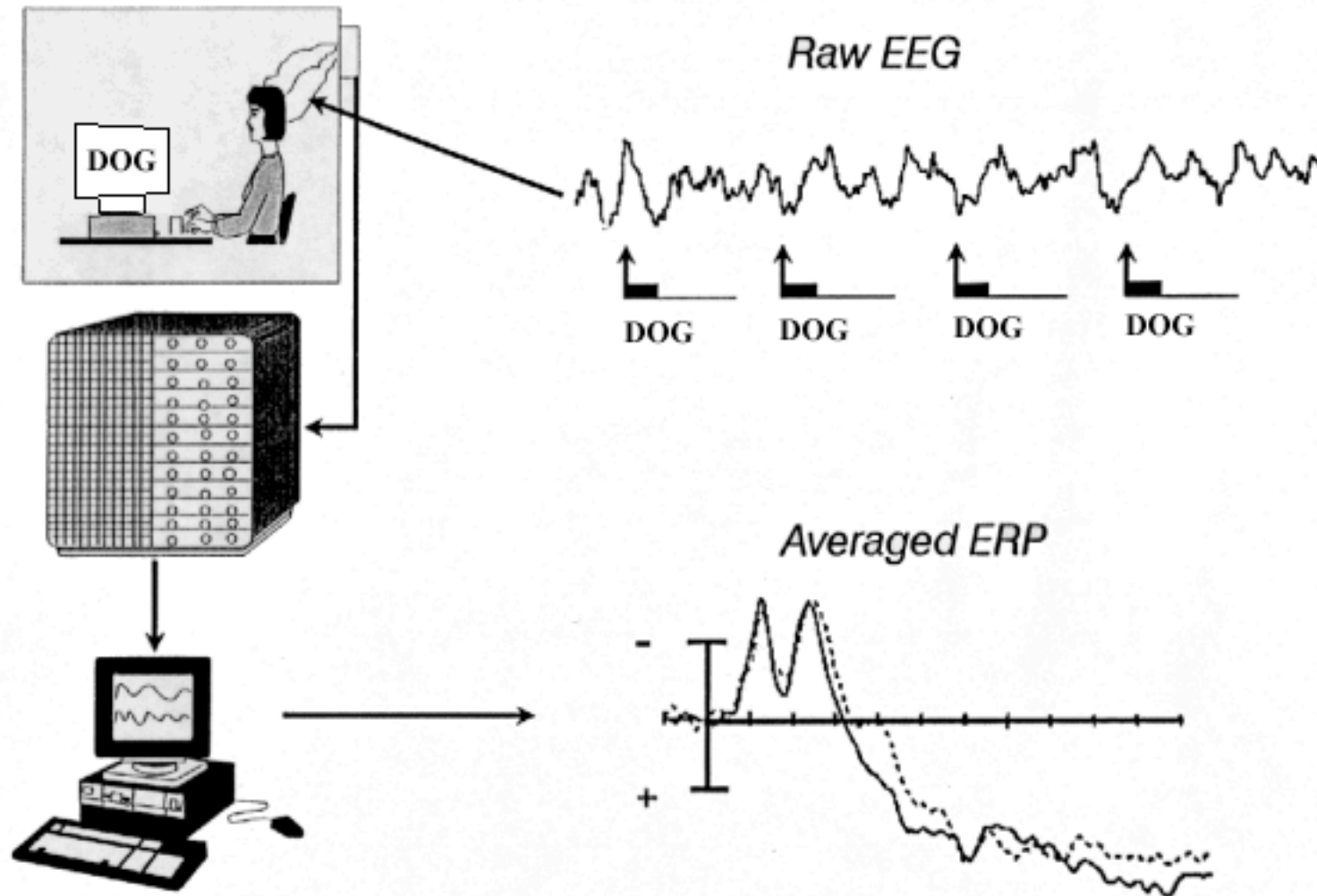
EEG



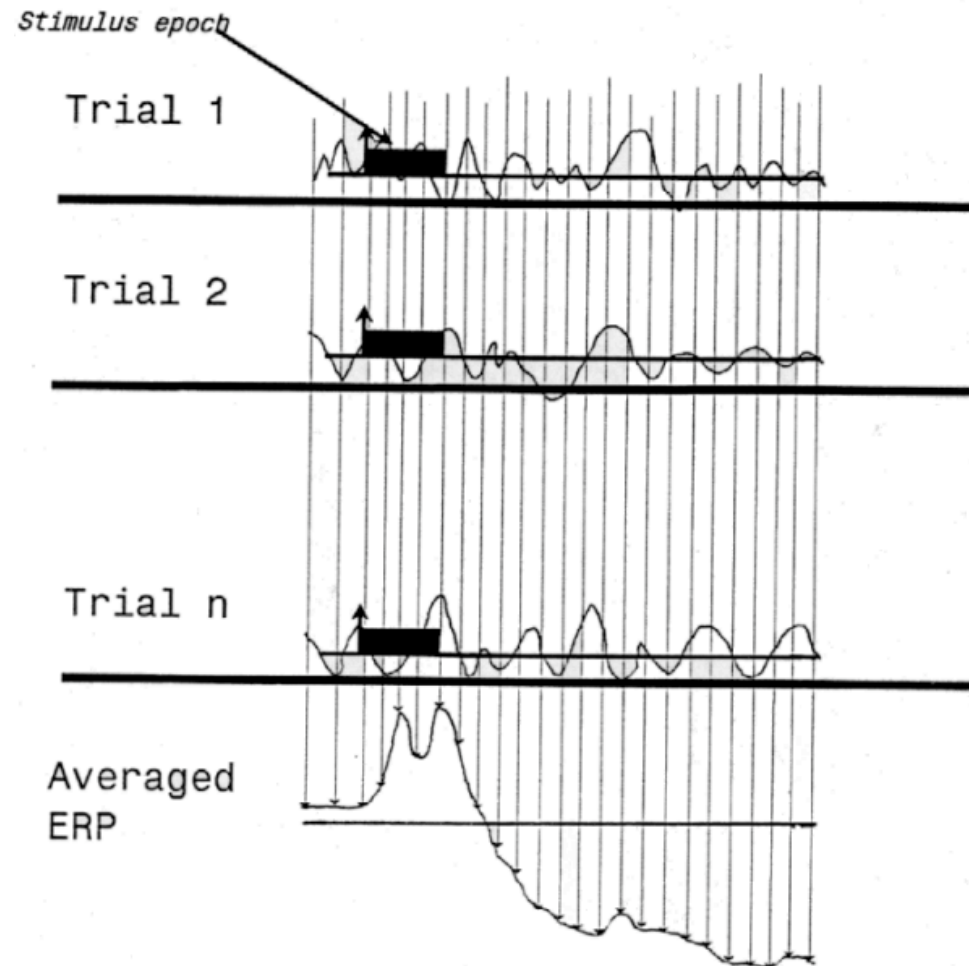
Event-Related Potential Technique



Event-Related Potential Technique



Averaging

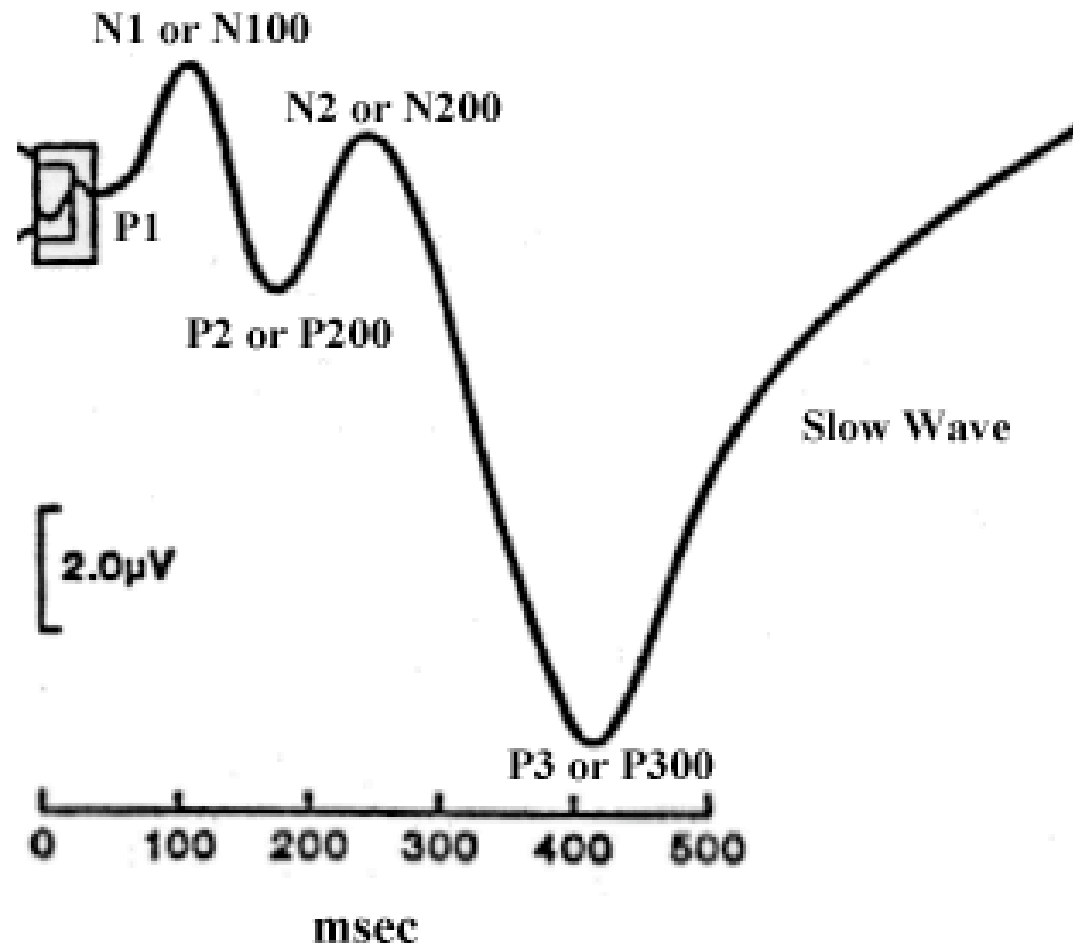


http://neurocog.psy.tufts.edu/images/ERP_averaging.gif

Labelling of ERP components

(warning: a bit confusing)

- P or N: whether the component is negative or positive going.
- Number after the letter: indicates the approximate peak latency of the components. 1, 2, 3, etc. are short for 100ms, 200ms, 300ms and so forth.
- Traditionally, negative is plotted up and positive down.

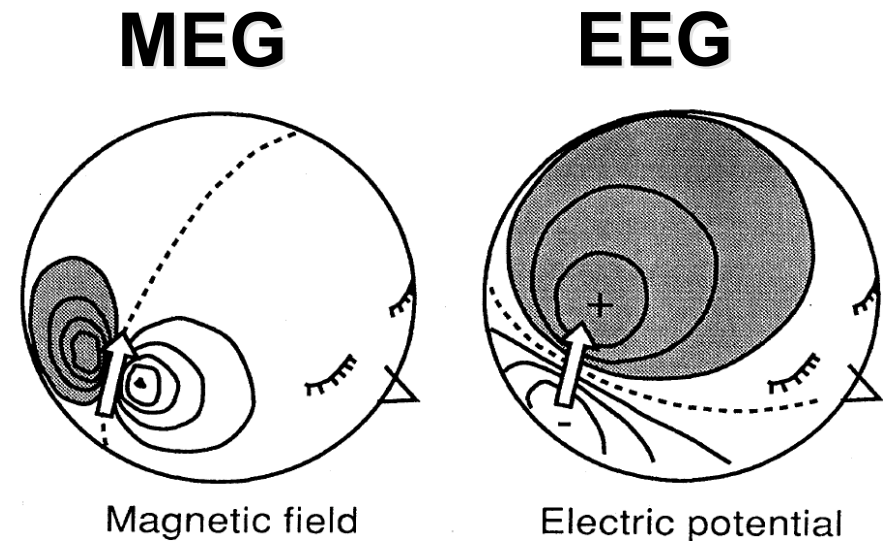
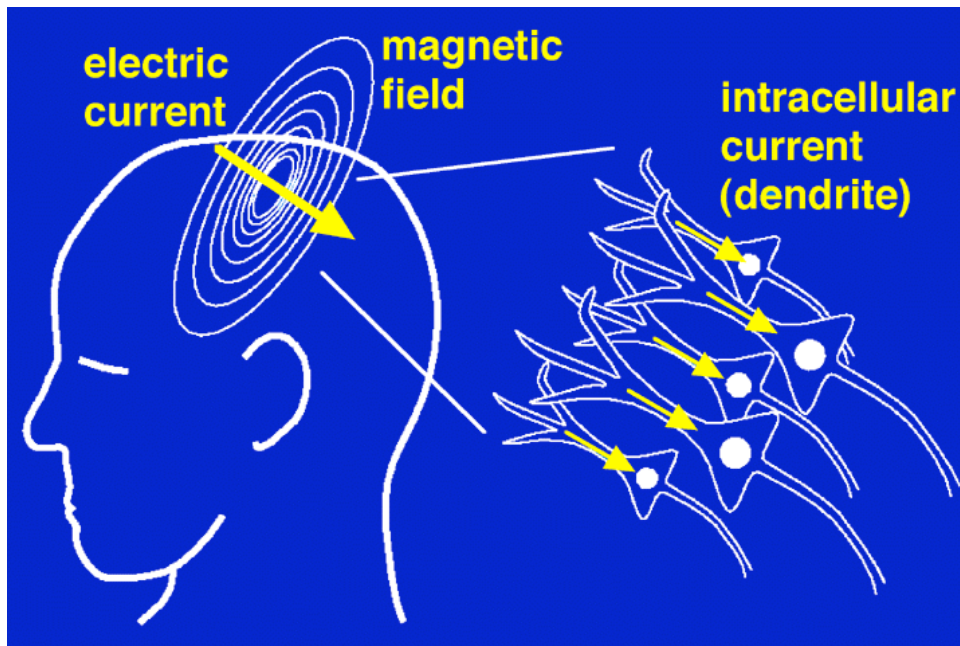


Temporal and spatial resolution of EEG

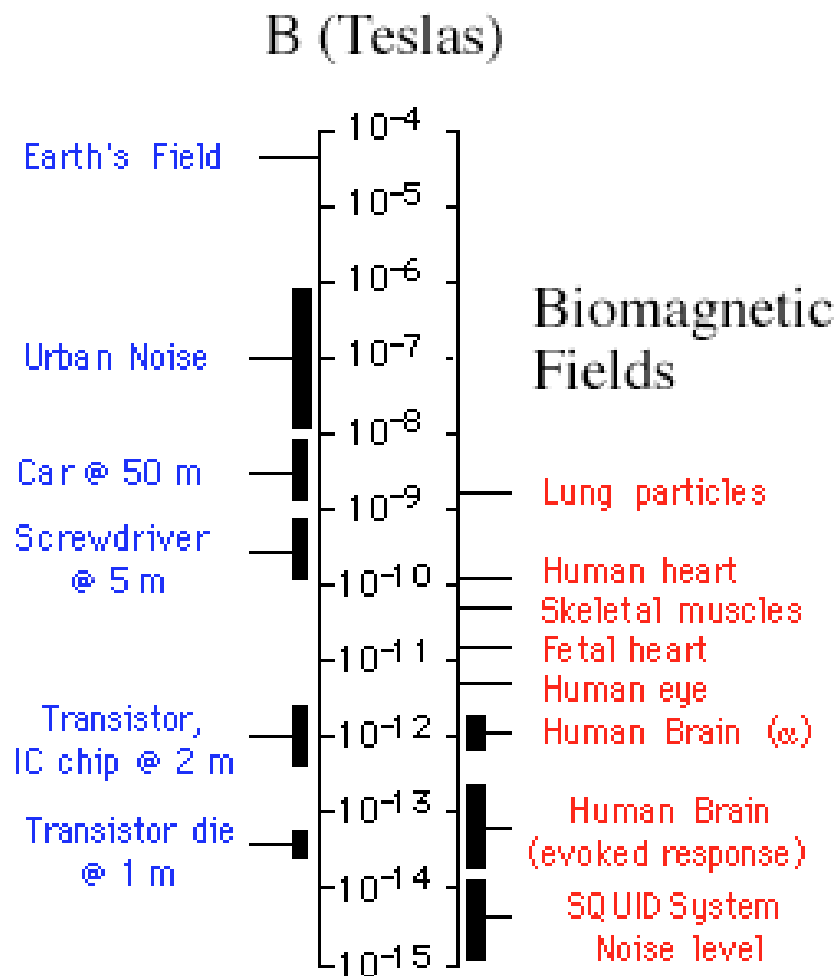
- Millisecond temporal resolution.
- Localization of neural generators complicated (and usually not done).
 - **Different tissues and the skull differ in their conductivity: Electric potentials do not pass through these structures undistorted.**
 - Localization requires realistic head models.

MEG

- Main advantage over EEG: better spatial resolution (millimeters for cortex, worse for deeper sources)
- Magnetic fields pass through skull and various tissues undistorted.
- Distribution of the magnetic field around the head tells you a lot about the underlying current generators.



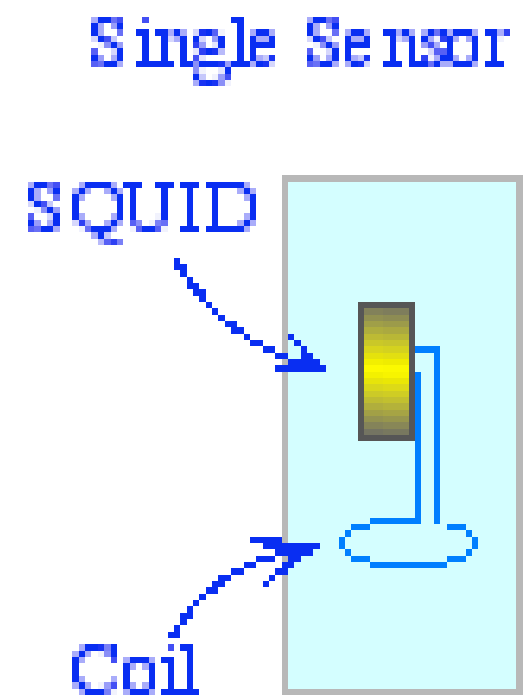
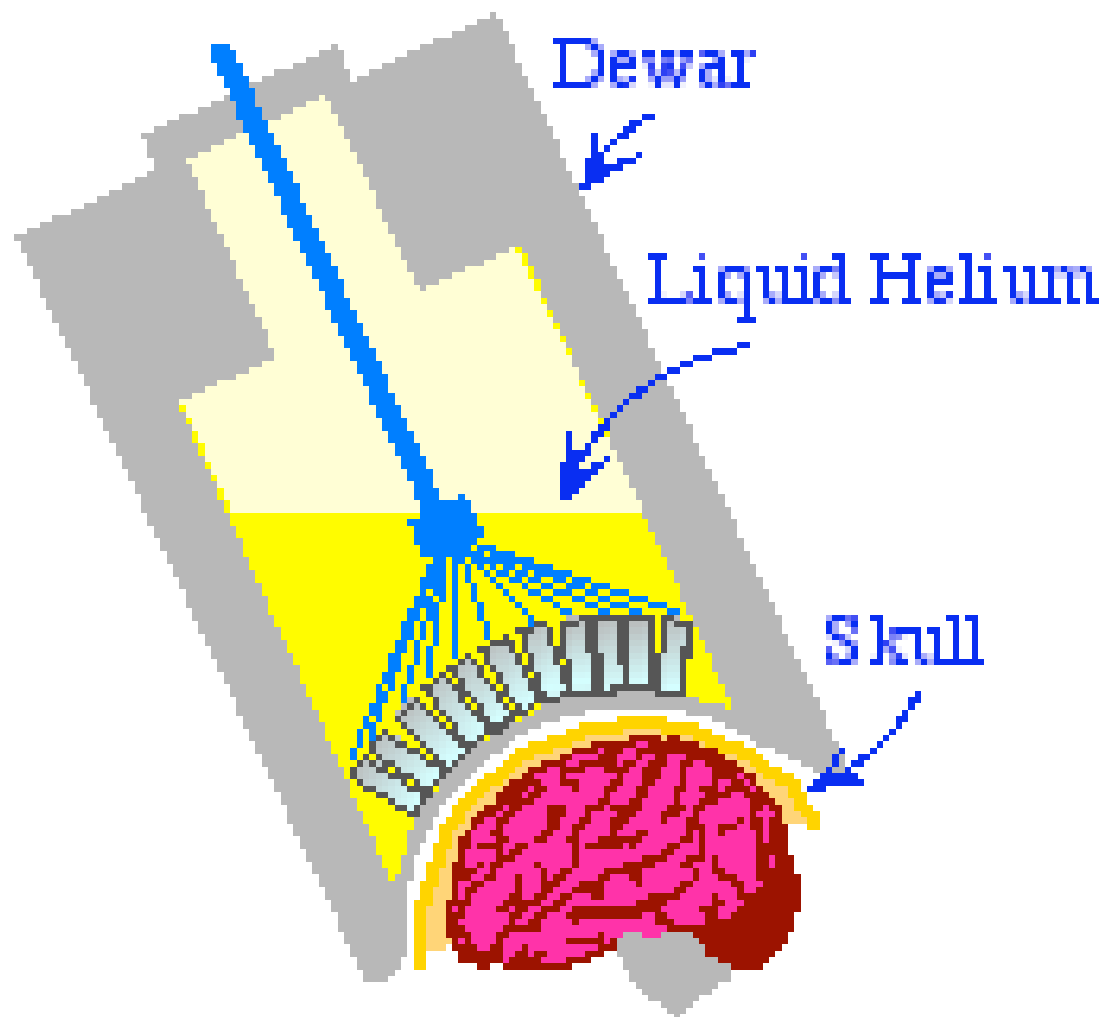
Magnetic Fields



The magnetic fields generated by neural activity are 100 million times smaller than the earth's magnetic field and 1 million times smaller than the magnetic fields produced in an urban environment.

How to capture the tiny signal

- Superconductive sensors
- Reference channels
- Magnetically shielded room



Reference channels

Placed somewhere close to the head but far enough to not measure any brain activity. Signal measured by the reference channel subtracted from the raw data usually online during acquisition.

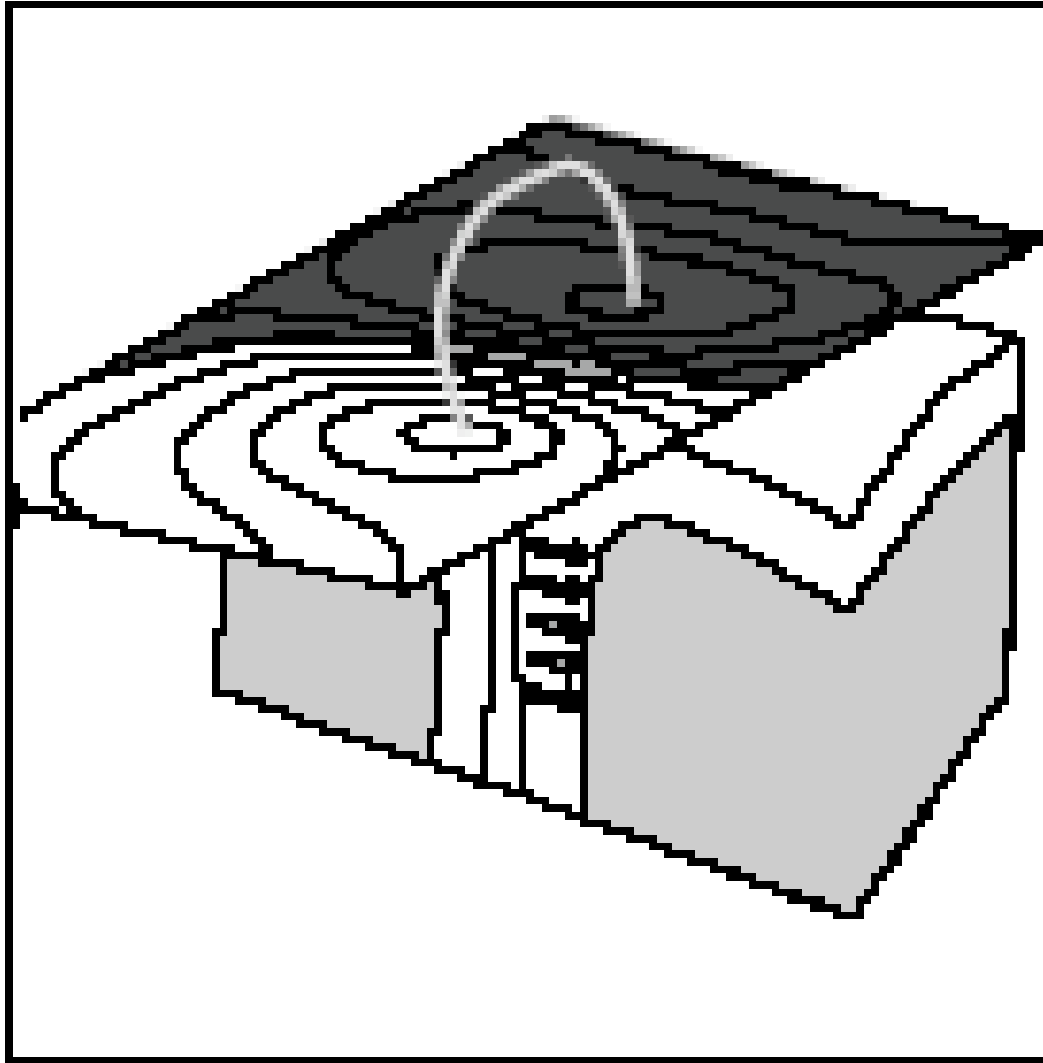


Magnetically shielded room (MSR)



Magnetically shielded room (MSR)

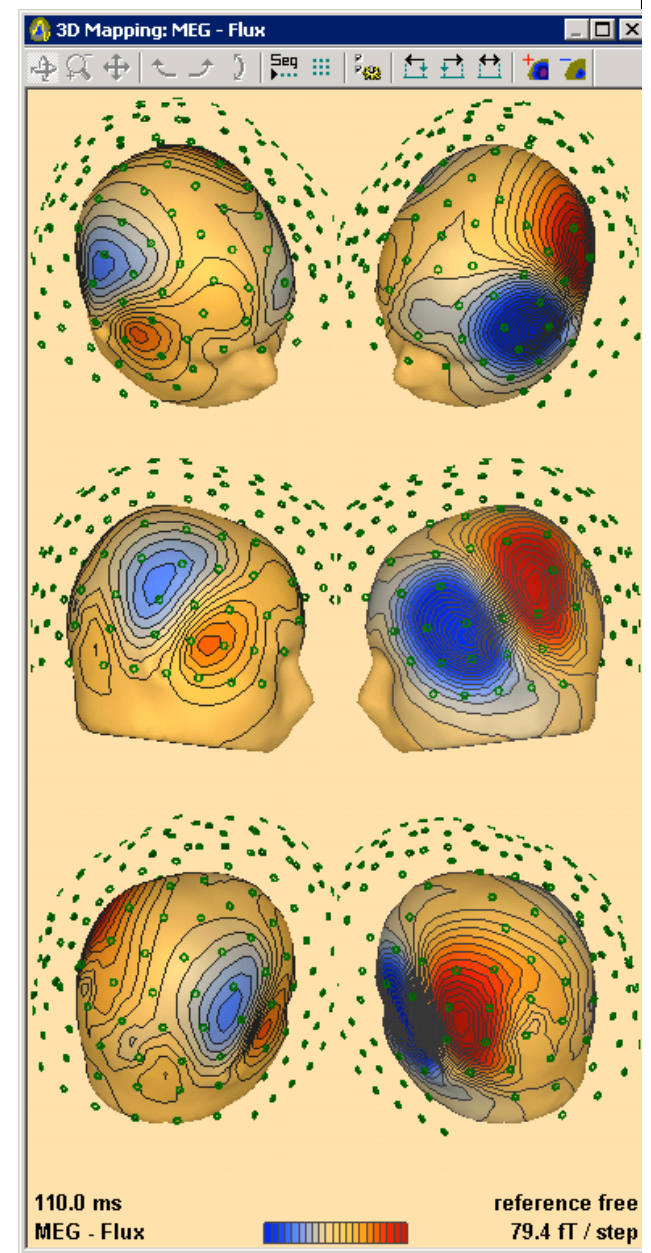
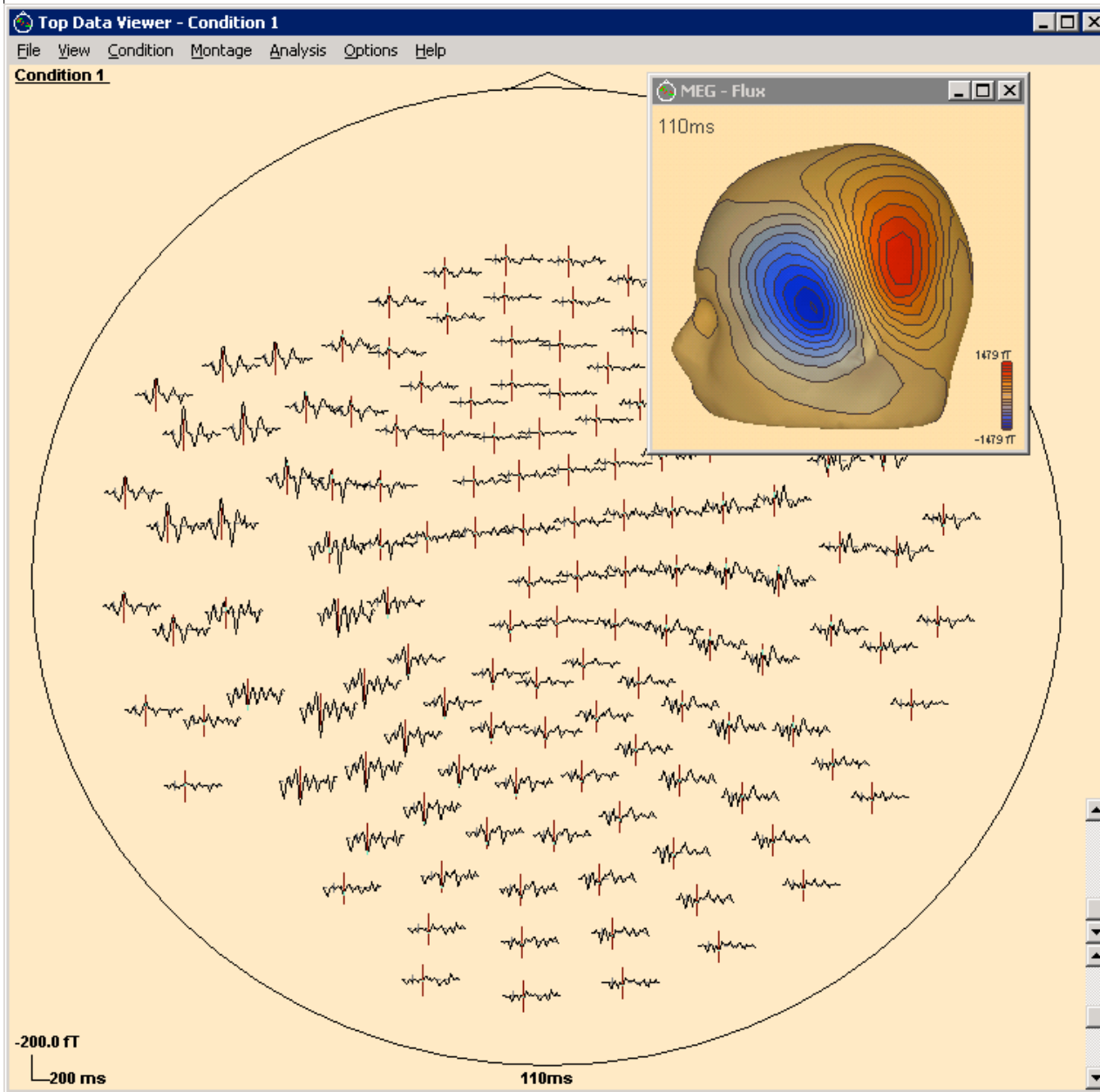




Source: <http://www.allgpsy.unizh.ch/graduate/mat/180102/Lecture1.pdf>

An averaged response to a 1kHz tone

Magnetic field at 110ms
= auditory M100

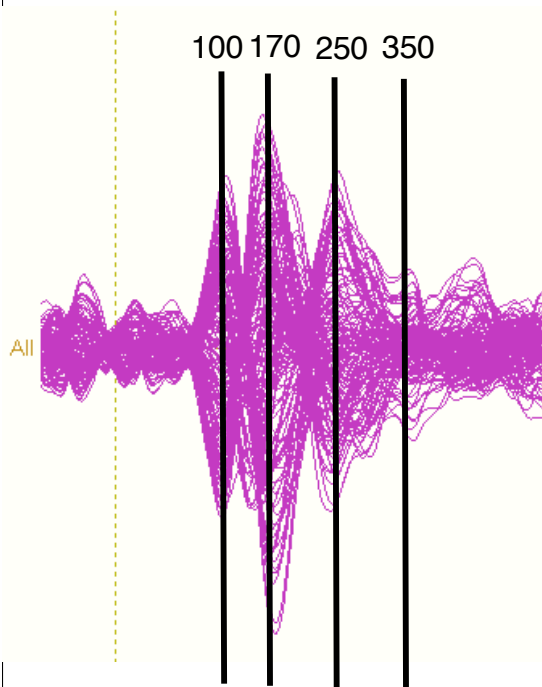


Labelling of MEG response components

- M50, M100, M250, etc...
- M = magnetic
- Like in ERPs, the number refers to the approximate peak latency of the components

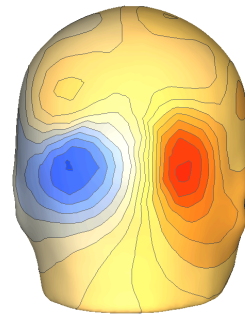
MEG components elicited by visual words

Averaged response to visual words



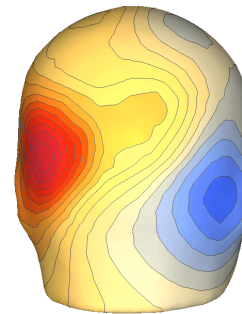
M100

100-150ms



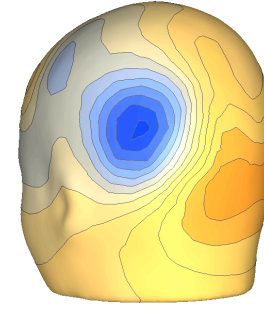
M170

150-200ms



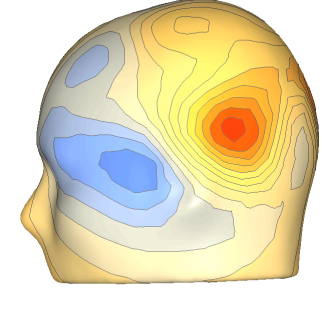
M250

200-300ms



M350

300-400ms

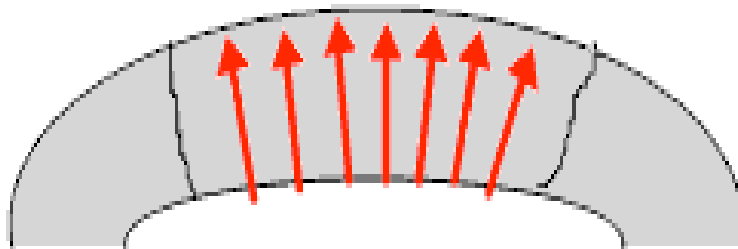


We can analyze:

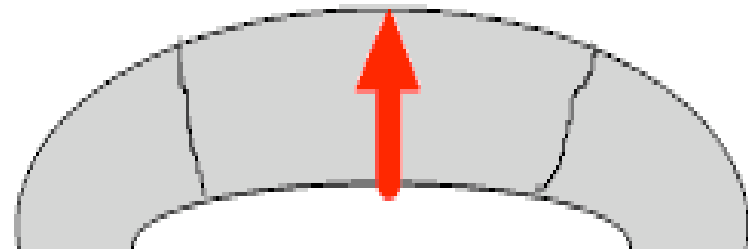
- either the sensor data (on the left)
- or the activity of the currents underlying the magnetic fields. The locations and orientations of these currents have to be modeled on the basis of the magnetic field distribution.
- Estimating the current source that generates a given magnetic field is called the *inverse problem*

The single dipole model

Active cortex modelled as dipole layer



Active cortex modelled as single dipole

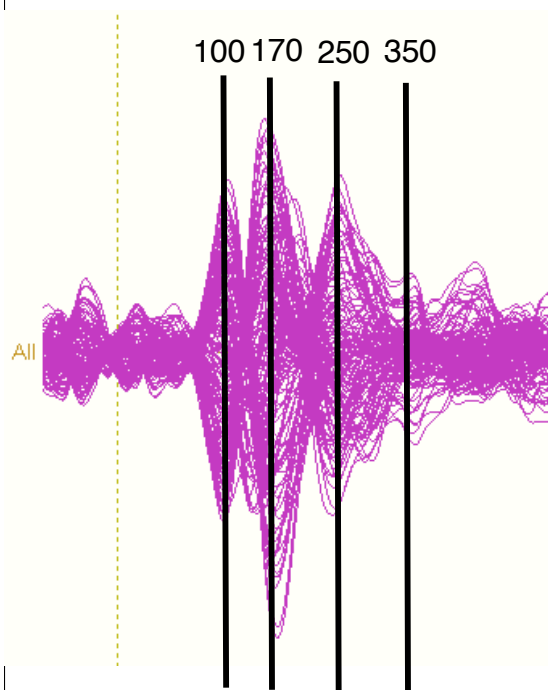


A discrete source model. Assumes that activity is generated not by a patch of cortex, but by point source. A good way to reduce the spatial dimensionality of the data. Each dipole acts as a spatial filter on the data.

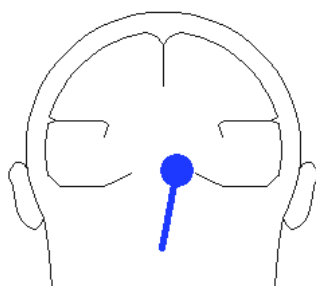
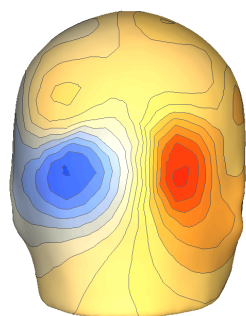
MEG components elicited by visual words

Dipole models

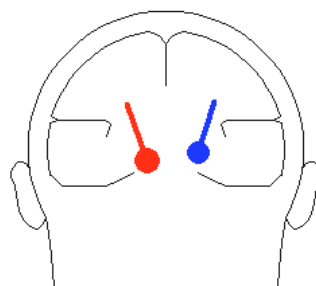
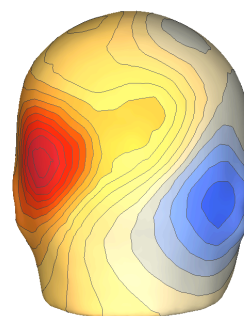
Averaged response to
visual words



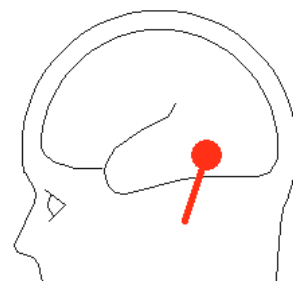
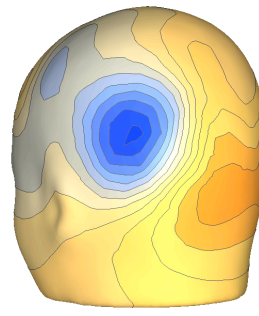
M100
100-150ms



M170
150-200ms



M250
200-300ms



M350
300-400ms

